

# Effect of LEO Cycling at Shallow Depths of Discharge on MANTECH IPV Nickel-Hydrogen Cells

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SHALLOW DEPTHS OF DISCHARGE OF MANTECH IPV  
NICKEL-HYDROGEN CELLS (NASA) 9 p CSCL 10A

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## EFFECT OF LEO CYCLING AT SHALLOW DEPTHS OF DISCHARGE

### ON MANTECH IPV NICKEL-HYDROGEN CELLS

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#### ABSTRACT

An individual pressure vessel nickel-hydrogen battery is being considered as an alternate for a nickel-cadmium battery on the Hubble Space Telescope. The space telescope battery will primarily be operating at a shallow depth of discharge (10 percent DOD) with an occasional 40 percent DOD. This shallow DOD raises several issues: (a) What is the cycle life? It is projected to be acceptable; however, there is no reported real time data base for validation. (b) The state of charge of the nickel electrode at the beginning of charge is 90 percent. Will this cause an acceleration of divergence in the battery individual cell voltages? (c) After prolonged cycling at 10 percent DOD, will there be enough capacity remaining to support the 40 percent DOD? (d) Is the state of charge really 90 percent during cycling?

There is no reported real time data base at shallow depths of discharge. The purpose of this investigation was to initiate a data base to address the above issues.

#### INTRODUCTION

A nickel-hydrogen battery is being considered as an alternate to a nickel-cadmium battery for the Hubble Space Telescope. For this application the battery will be operated at a shallow depth of discharge (10 percent) with an occasional modest depth of discharge (40 percent) (1). Several issues have been raised pertaining to mission suitability such as: (a) Is there capacity degradation on battery storage? This is relevant since nickel-hydrogen batteries could be subjected to prolonged periods of scheduled or unscheduled storage prior to launch. (b) What is the cycle life at this shallow depth of discharge? It is projected to be adequate to meet low earth orbit missions requiring 30 000 cycles (2). However, there is no reported real time data base for validation. (c) What influence will the shallow depth of discharge have on divergence in the battery individual cell voltages? This is relevant to frequency of battery reconditioning. (d) After prolonged cycling at 10 percent DOD will there be enough capacity reserve to support the required 40 percent

DOD? And (e) is the state of charge really 90 percent during cycling?

There is no reported real time data base at shallow depths of discharge. There is an accelerated cycle life test (two times the normal charge and discharge rate) at 15 percent DOD (Private communication from J. Brill, Eagle Picher); however it is questionable to extrapolate these results to predict real time battery performance. The intent of this investigation is to initiate a real time data base to address the above issues.

#### EXPERIMENTAL

##### Test Facility

The test facility used to cycle life test the nickel-hydrogen cells is illustrated in Fig. 1. The facility design incorporates two main features: safety and versatility. Since the nickel-hydrogen cells are precharged with hydrogen and also generates hydrogen during charge, special attention was given to personal safety. The cells were located on top of the instrumentation cabinets. There were two cells for each cabinet. Each cell was located within a cylindrical shrapnel shield in case of the improbable event of an explosion or rupture of the cell pressure vessel. During a test, the cylindrical shield was purged with nitrogen to create an inert atmosphere. The nitrogen gas, and hydrogen gas if any, would be exhausted from the test laboratory through a hood located above the cells. If the exhaust fan would fail or the nitrogen purge would become interrupted the test would be automatically terminated. A test can also be terminated on a preset upper and/or lower limit of cell voltage, current, pressure, and temperature.

The facility's versatility allows for testing over a wide range of cycle regimes. A geosynchronous earth orbit (GEO) cycle regime can be run in real time using a programmable timer. Various accelerated GEO and low earth orbit cycle regimes can be run using a Texas Instrument timer. The cell discharge current is controlled by an electronic load, which can be varied from 0 to 100 A. The charge current can also be varied in the same range. Test data is printed out locally using a Fluke data collector. Strip chart recorders are used

to record cell voltage, current, and pressure as a continuous function of charge and discharge time for selected cycles. A maximum of twelve cells can be tested at the same time.

#### TEST CELL DESCRIPTION

The three cells were 50 A-hr capacity space weight IPV nickel-hydrogen cells. They were manufactured by Yardney Electric Corporation (Battery Division) according to specifications directed under the Air Force (WPAB) manufacturing technology contract with Yardney (3). The cell is illustrated in Fig. 2. It consists of a stack of nickel electrodes, separators, hydrogen electrodes, and gas screens assembled in a non back-to-back electrode configuration. In this configuration electrodes of different types directly face each other. The stack is packaged in a cylindrical pressure vessel, with hemispherical end caps. This is made of Inconel 718 and lined with zirconium dioxide which serves as a wall wick. The components are shaped in a "pineapple" slice pattern. The electrodes are connected electrically in parallel. A dual separator, consisting of one layer of asbestos and one layer of zircar, is used. Hence, since a high bubble pressure asbestos separator is used, the oxygen generated at the nickel electrode on charge is directed to the hydrogen electrode on the next unit cell, where it combines chemically to form water. The zircar separators are extended beyond the electrodes to contact the wall wick. Hence electrolyte which leaves the stack during cycling will be wicked back into the stack. The gas screens are polypropylene. The electrolyte is a 31 percent aqueous solution of potassium hydroxide. The nickel electrode consisted of a nickel slurry plaque containing a nickel screen substrate which was electrochemically impregnated by the aqueous Siger/Puglisi process (4). The cells were precharged with hydrogen to a pressure of 14.5 psia.

#### Measurements and Procedures

For this experiment the quantities measured for each cell at the end of charge and discharge, and their accuracies were: Current ( $\pm 0.3$  percent), voltage ( $\pm 0.5$  percent), pressure (1 percent), and temperature ( $1^\circ\text{C}$  limit of error). Additional measurements were charge and discharge ampere-hours ( $0.5$  percent) and charge to discharge ampere-hour ratio. Cell current, voltage, pressure, and temperature were recorded continuously as a function of time, for selected cycles, on a strip chart recorder.

Cell charge and discharge currents were measured across a shunt, using an integrating digital voltmeter. Cell voltage was also measured using an integrating digital voltmeter. Cell pressure was measured using a strain gauge located on the cell dome. The temperature was measured using an iron-constantan thermocouple located on the center of the pressure vessel dome. The thermocouple was mounted using a heat sink compound to insure good thermal contact. Charge and discharge capacity was measured using an ampere-hour meter. Charge to discharge ratio (ampere-hour into cell on charge to ampere-hours out on discharge) was calculated from the ampere-hour measurements.

For the storage test the cells were discharged at the C/10 rate (5 A) to about 0.1 V or less. Then the cell precharge hydrogen pressure was set by the manufacturer to 0 psig (14.5 psia). After undergoing activation and acceptance test, the cells were once again discharged at the C/10 rate (5 A) to 0.1 V or less. The terminals were shorted. The cells were shipped to NASA Lewis where they were stored at room temperature in the shorted condition for 1 year. After

storage the acceptance test was repeated at NASA Lewis. The tests consisted of measuring the discharge ampere-hour capacity. The discharge capacity was measured after charging the cell at the C/10 rate (5 A) for 16 hr, followed by a 1 hr open circuit voltage stand. The discharge capacity was measured at the C/2 rate (25 A) to 1 V.

Cell history prior to the LEO, 10 percent DOD cycle test was as follows: The cells were tested under a 90 min LEO cycle regime at deep to modest depths of discharge (80, 60, and 40 percent). Results of the 80 percent and partial results of the 60 percent DOD test were reported previously (5). The cells performed poorly at the 80 percent DOD. They failed on the average at cycle 741. After failure the cells were reconditioned which consisted of: (a) Deep discharge - cells were discharged at C/2 rate to 1.0 V or less and (b) a combination of open circuit stand and deep discharge reconditioning. The cells were left on open circuit stand for 28 days. Then the cells were deep discharge reconditioned as stated above. After reconditioning, the cells were placed back on cycling at 80 percent DOD. When the cells failed after a second attempt to recondition the DOD was reduced to 60 percent and the cycle test continued. After failure the DOD was reduced to 40 percent. At about 1440, 40 percent DOD cycles, the cell voltage was stable, however the DOD was reduced to 10 percent to address issues raised about battery performance at shallow depths of discharge.

Prior to initiation of the cycle life test at 10 percent DOD the cells were deep discharge reconditioned. The cycle regime was a 90 min LEO consisting of a 55 min charge immediately followed by a 35 min discharge. For the first test cycle the cells were charged for 18 hr at the C/10 rate (5 A) followed by discharge at the 0.171 C rate (8.57 A) for 35 min. Then the normal 10 percent DOD LEO charge/discharge cycling was initiated, which consisted of charging the cells at a constant 0.12 C rate (6.0 A) for 55 min immediately followed by discharge at a constant 0.171 C rate (8.57 A) for 35 min. The charge to discharge ratio was set at 1.10 and maintained at this level for the duration of the test. During the cycle life test the temperature was maintained at  $20 \pm 3^\circ\text{C}$ .

#### RESULTS AND DISCUSSION

##### Storage test

The effect of storage (1 year, terminals shorted) on the capacity of three, 50 A-hr space weight IPV nickel-hydrogen cells is summarized in Fig. 3. The spread in the data indicate there is no significant capacity loss due to the 1 year storage. This information is relevant to applications where the battery is in planned or unplanned storage (launch delay) for up to 1 year. It is also advantageous to store cells in the shorted condition, since this eliminates the potential hazard associated with high voltage.

The capacity of each cell after the storage was measured at the initial intended use rate (1.37 C = 68.5 A, 80 percent DOD) to a 1 V cut off. The results are shown in Table I. The average capacity of the three cells was 53 A-hr.

##### Cycle Test

The cells were cycled at four depths of discharge (80, 60, 40, and 10 percent). The results are summarized in Table II. Initially the cells were cycled at 80 percent DOD. At this DOD the cell performance was poor. On the average the cells failed at cycle 741.

The failure was characterized by a degradation of the end of discharge voltage to 1.0 V prior to the end of the 35 min discharge. For these cells the 80 percent DOD was apparently too stressful. In an attempt to improve cell performance, the cells were deep discharged and open circuit stand reconditioned. They were placed back on cycling at the 80 percent DOD; and once again failed due to the low end of discharge voltage. The reconditioning had a very limited beneficial effect. The DOD was reduced to 60 percent and the cycling was continued. The cells once again failed on the average after about 2000, 60 percent DOD cycles due to low end of discharge voltage. The DOD was reduced to 40 percent and the cycle test continued. At this DOD the performance improved, the end of discharge voltage was stable; however after 1441 cycles the DOD was reduced to 10 percent to address issues raised at a Hubble Space Telescope meeting.

The influence of cycling (10 percent DOD) on the end of discharge voltage for the three cells is shown in Fig. 4. The initial decrease in voltage is an effect of reconditioning prior to this test. After reconditioning there is usually a short lived voltage improvement. The cells, in the continuing test, have been cycled on the average for 3573 cycles (10 percent DOD) and as expected are performing satisfactorily. At this shallow depth of discharge the cycle life is projected to meet LEO mission requirements in excess of 30 000 cycles (5 years) (2). The continuing test is required to validate this projection since there is no other reported real-time data base at shallow depths of discharge. As stated previously, there is an accelerated cycle life test (two times the normal charge and discharge rate) at 15 percent DOD, however it is questionable to extrapolate these results to predict real time battery performance. The spread in the data in Fig. 4 shows that there is no significant divergence in end of discharge voltage. The issue of cell divergence was raised since the cells are at a 90 percent state of charge when charge is initiated. This is relevant to frequency of battery reconditioning in applications requiring a shallow depth of discharge.

After prolonged cycling at 10 percent DOD the cells were discharged to a 40 percent DOD to verify they had adequate capacity reserve to support this DOD. The test results, shown in Table III indicate they could sustain the 40 percent DOD.

Is the state of charge (SOC) really 90 percent during cycling? To address this issue, after the 40 percent DOD test described in the previous paragraph, the discharge was continued at the 40 percent DOD rate beyond 35 min to 0.1 V; then the rate was reduced to C/10 (5 A) and the discharge continued to 0.1 V. The ratio of this total capacity to the total capacity at the start of the 10 percent DOD test is

defined as the SOC. The test results are shown in Table III and indicate that the cells at the beginning of the 40 percent DOD test were at, on the average, a 99 percent SOC. From this data it can be inferred that the cells are at a 90 percent SOC during cycling at 10 percent DOD.

#### CONCLUDING REMARKS

The influence of storage and LEO cycling at various depths of discharge (80, 60, 40, and 10 percent) on the performance of Yardney MANTECH 50 Ah capacity flight weight IPV nickel-hydrogen cells was investigated. No performance degradation was observed due to a one year storage (hydrogen pressure 14.5 psia, terminals shorted). On the average the cycle life was 741 cycles at 80 percent DOD and 2000 cycles at 60 percent DOD. At the 40 percent DOD the cells were not cycled to failure. After about 1440 cycles they were performing well, however the DOD was reduced to 10 percent to address issues relevant to shallow depth of discharge applications such as the Hubble Space Telescope. The cells, as expected, are performing satisfactorily at the shallow depth of discharge; after 3573 cycles there is no significant degradation or divergence in end of discharge voltage in the continuing test. After about 1764, 10 percent DOD cycles the cells successfully supported a 40 percent DOD.

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TABLE I. - CAPACITY OF YARDNEY MANUFACTURING TECHNOLOGY  
SPACE WEIGHT IPV NICKEL-HYDROGEN CELLS  
AFTER 1 YEAR STORAGE

Cell	Capacity, A-hr <sup>a</sup>	V <sub>EOD</sub> , V <sup>b</sup>	Discharge current, A	Temperature °C
1	52.5	1.0	68.5	23
2	53.7	1.0	68.5	23
3	53.0	1.0	68.5	23

<sup>a</sup>After charge 16 hr at C/10 (5 A).

<sup>b</sup>V<sub>EOD</sub> ≡ End of discharge voltage (V).

TABLE II. - SUMMARY OF CYCLE TEST RESULTS FOR YARDNEY MANTECH  
50-Ah IPV FLIGHT WEIGHT NICKEL-HYDROGEN CELLS

Depth of discharge, percent	Cell			Remarks
	1	2	3	
	Cycle			
80	734	750	735	Cell failed <sup>a</sup>
80	354	620	598	Reconditioning cycles
60	1992	2005	1954	Cell failed
40	1444	1439	1441	Depth of discharge reduced to 10 percent
10	3505	3607	3608	Test continuing
	8029	8421	8336	Cumulative cycles

<sup>a</sup>Cell failure was defined to occur when the discharge voltage degraded to 1.0 V during the course of the constant current 35 min discharge.

TABLE III. - SUMMARY OF 40 PERCENT DEPTH OF DISCHARGE  
RESULTS AFTER PROLONGED CYCLING AT  
10 PERCENT DEPTH OF DISCHARGE

Cell	Cycle <sup>a</sup>	Depth of discharge, percent	Discharge time, min	V	SOC <sup>b</sup>
1	1759	40	35	1.16	99
2	1766	40	35	1.16	100
3	1766	40	35	1.17	98

<sup>a</sup>10 percent depth of discharge cycles.

<sup>b</sup>SOC = state of charge prior to 40 percent depth of discharge test.

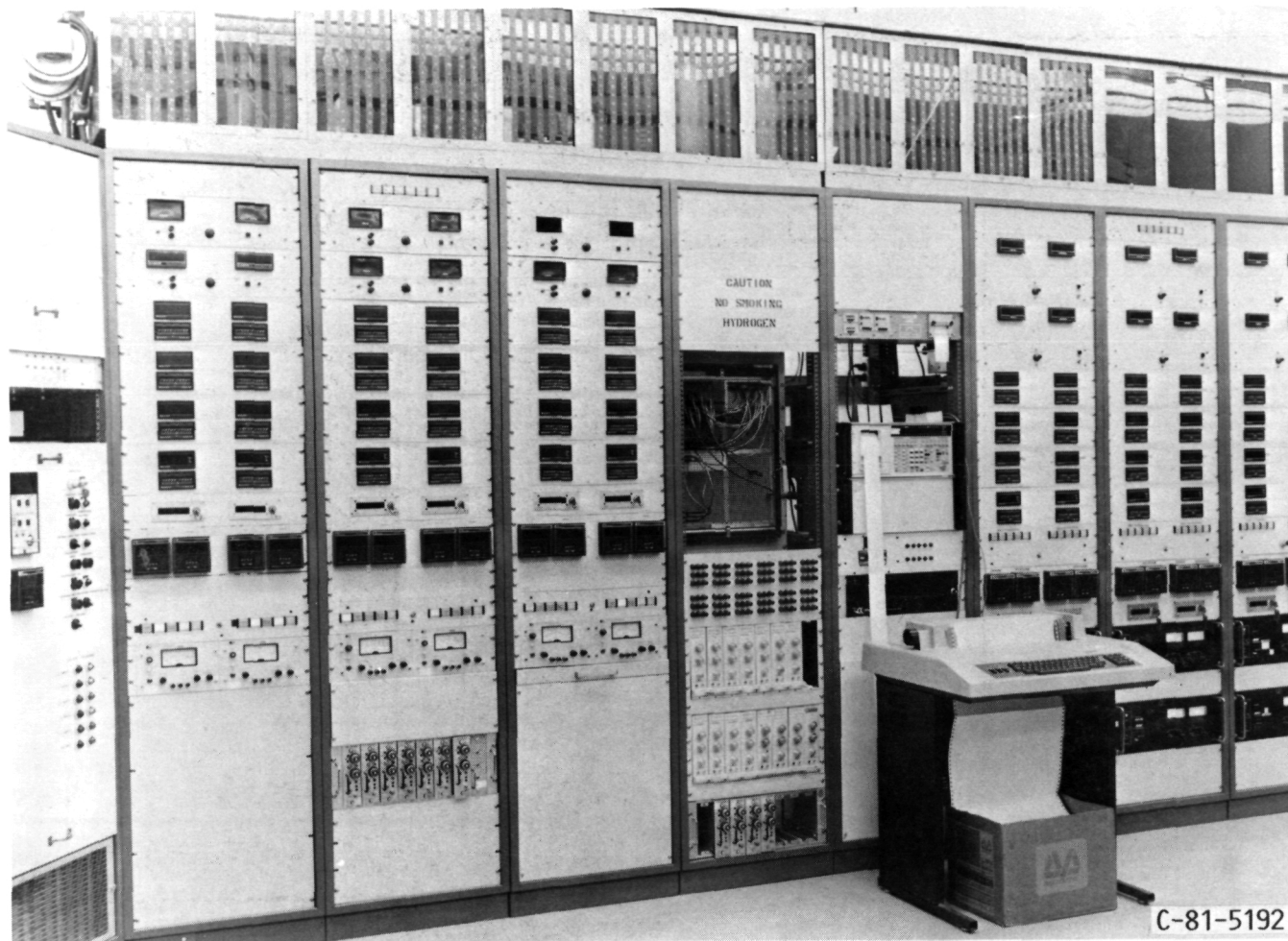


FIGURE 1. - NICKEL-HYDROGEN CELL TEST FACILITY.

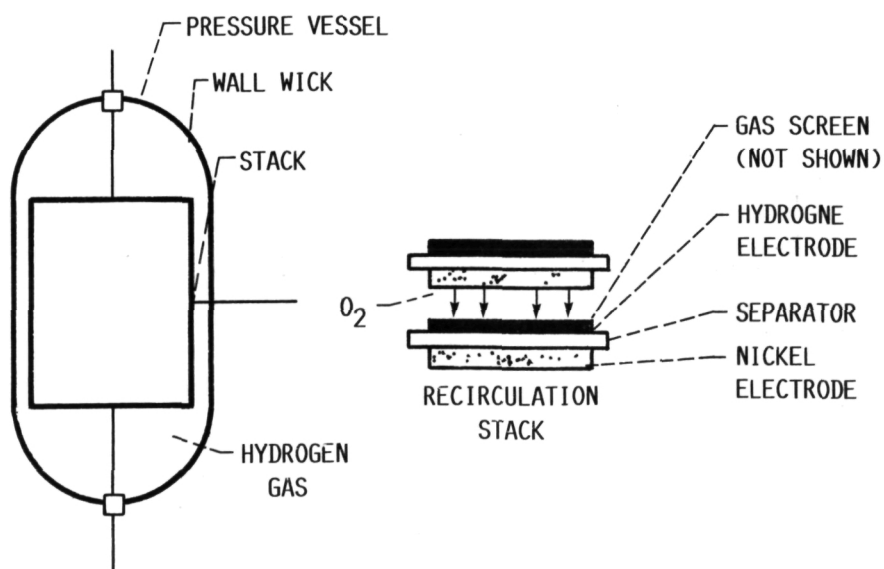


FIGURE 2. - ILLUSTRATION OF YARNEY MANUFACTURING TECHNOLOGY INDIVIDUAL PRESSURE VESSEL NICKEL-HYDROGEN CELL.

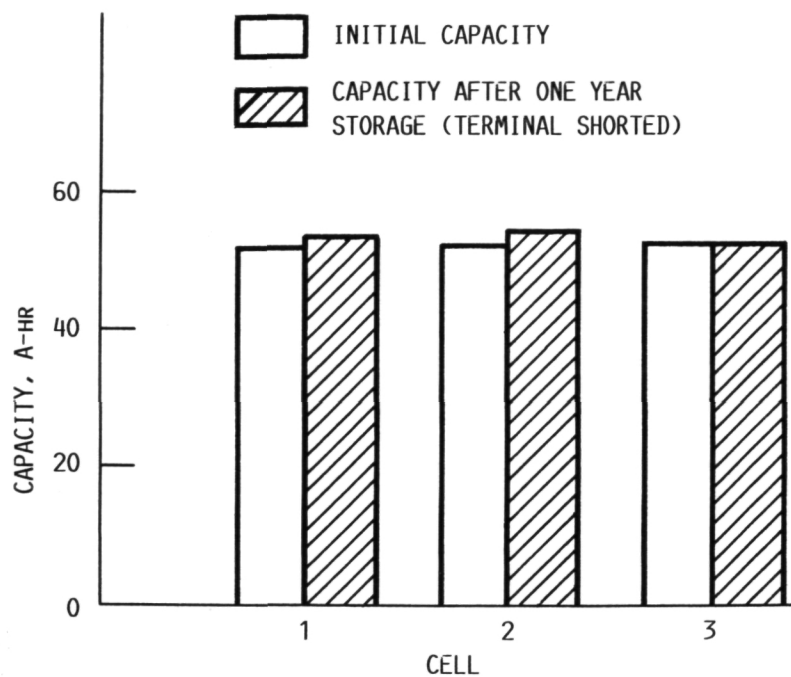


FIGURE 3. - EFFECT OF STORAGE ON CAPACITY OF 50AH YARDNEY SPACE WEIGHT IPV  $\text{Ni}/\text{H}_2$  CELLS.

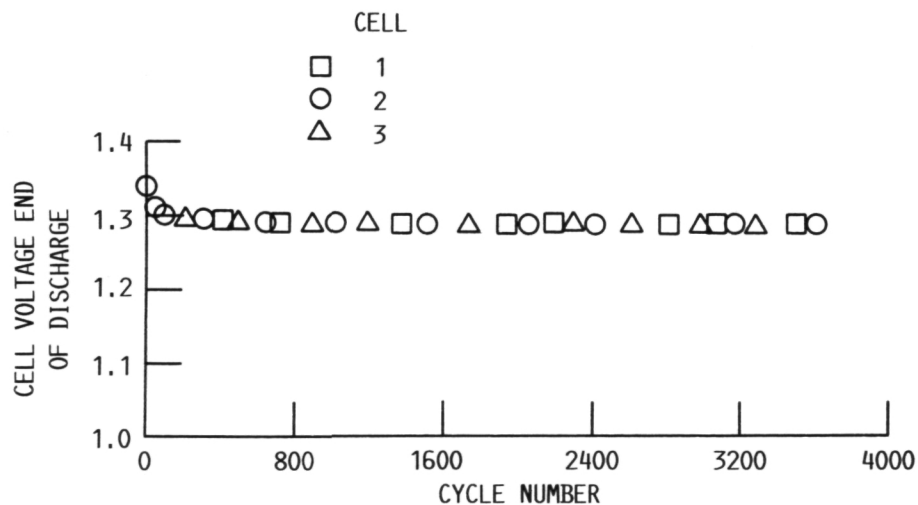


FIGURE 4. - EFFECT OF CYCLING ON END OF DISCHARGE VOLTAGE OF YARDNEY MANTECH 50 AH FLIGHT WEIGHT NICKEL HYDROGEN CELLS.

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